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ENERGY COST OF TREADMILL WALKING COMPARED TO ROAD WALKING

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ENERGY COST OF TREADMILL WALKING COMPARED TO ROAD WALKING

Abstract: A comparison has been made between subjects walking at 3-1/2 mph on the treadmill and walking over roads and cinder tracks at the same speed. It has been found that the road or cinder track condition involves an average energy expenditure nine to ten percent greater than that for the treadmill. This is believed to be caused by a difference in the body mechanics while walking under these two different conditions. This difference must be taken into account in extrapolating climatic chamber and other treadmill data to field conditions.

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Foreword: The physiologic response to a standard work task is a well accepted and widely used index for estimating a) the ability of man to perform physical work, and b) the degree of deterioration resulting from exposure to stress situations. Miniature work tasks and the motor driven treadmill are the most commonly used methods of presenting a standard work task. The ultimate goal of such research is to estimate, from data derived under controlled laboratory conditions, the degree of changes that may be expected to occur under naturally occurring conditions of work and exposure to stress. In order to apply the results from controlled laboratory experiments to natural situations it must be either assumed or proved that the responses of man are the same in the two instances. This sixth report in the series on the Physiology of Load-Carrying presents the basic data for comparison of one type of work task walking outdoors on a hard surfaced road with walking on a motor-driven treadmill in the laboratory.

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ENERGY COST OF TREADMILL WALKING COMPARED TO ROAD WALKING

1. Introduction

a. The motor-driven treadmill provides a convenient, accurate, and consistent means for producing various levels of physical activity. It is a means of exercise which, in effect, contains a built-in correction for differences in body size, since the work required of the test subject is proportional to his own weight. It is a form of exercise which is easily mastered, and since most subjects are in relatively good physical condition for walking they do not require extensive conditioning before studies are carried out. The treadmill, by allowing locomotion in one spot, permits exercise within the confines of climatic chambers or other indoor test rooms. Because the subject remains in one place, instrumentation can be connected to him for recording such physiological variables as pulse rate and respiratory rate; and expired air can easily be collected for determination of metabolic rate. As is evident in this report, the control of speed and the maintenance of constant speed are important considerations in employing a treadmill rather than an outdoor form of exercise in studies involving physical work.

b. Some of the parameters of response to treadmill walking, including the training factor, have been studied and discussed by Erickson, et al.[8]

c. Some of the early treadmills used for studies of locomotion consisted of a belt moving over a series of rollers.[4] More recent treadmills have had a leather or fabric belt moving over a hardwood slipway. The slipway apparently requires less training and provides better stability during walking.[5,8]

d. Many of the classic studies on the energy cost of walking at different speeds and with different loads were conducted on treadmills.[2,3] In one of these extensive studies, Smith[11] commented that differences presumably existed between treadmill walking and ordinary walking. His additional comment on the subject is appreciated by the present authors, "the problem of the difference in effect of walking in the open air as compared to walking on a treadmill in a well-ventilated room can only be solved by the use of impeccable technique." Smith mentioned that Durig had found treadmill walking to be more economical than forward walking; however, Durig's reports[4,5] appear to indicate that his treadmill (belt over rollers) required a higher energy expenditure than road walking. Atzler and Herbst[1] report a comparison of treadmill with road walking using one subject and concluded that the treadmill was about 1.2 percent higher than the road. Two readings were taken in each situation, one of the open road readings at a considerably lower value than the other three.

e. In the course of studies on load-carrying conducted at this Laboratory, we have compared a group of subjects carrying a 46-pound load at 3-1/2 mph on a treadmill with the same group carrying the same load and wearing the same clothing while walking over a level, asphalt road out of doors. An additional group of subjects were compared while wearing eight-pound nylon vest armor on the treadmill and on a cinder track.

2. Methods

a. Metabolic rate during walking on the treadmill was measured with a closed system Tissot spirometer supplying pure oxygen and having soda lime to reabsorb carbon dioxide. The studies conducted in the field were done by the Douglas Bag method, the volume of expired air in the Douglas Bag was measured with a dry gas meter, and the air analyzed for oxygen and carbon dioxide by the Haldane method. A systematic comparison, using two subjects, was made between the closed system Tissot spirometer and the open system Douglas Bag method to assure the equivalence of these methods in this Laboratory. While the subject walked on the treadmill the mouthpiece was first connected to the closed system, then the Douglas Bag, then the closed system again in continuity. By this means two closed system readings were obtained which immediately bracketed the open system collection.

b. The treadmill studies were carried out at a room temperature of 19°C. (66°F.). The outdoor studies were conducted on sunny days in November 1951, with air temperatures from -4° to 10°C. (25° to 50° F.)

c. The outdoor walking course was a "black-top" road. The subjects walked over 2400 feet of surface which was apparently level (less than 1/8 percent grade by clinometer), 600 feet of a two percent grade, and 2400 feet of a 1/4 percent grade. The Douglas Bag collections were made on the level stretch, the direction of travel being alternated.

d. The speed of the treadmill was calculated by measurement of the belt length and counting revolutions. In the outdoor portion of the study, speed was controlled in the following manner: markers were placed at 800-foot intervals; an observer practiced pacing these intervals at 3-1/2 mph (93.48 meters/minute). This investigator then paced the subjects, his time being checked by another observer with a stop clock. The exact time required to walk 800 feet at 3-1/2 mph was 2 minutes and 35.8 seconds. If the subjects failed to complete the 800 feet within 2 minutes 35 seconds and 2 minutes 37 seconds, the run was discarded. With practice and constant time checks, the pacing of this procedure became quite consistent and accurate.

e. In both indoor and outdoor studies the subjects wore cotton shorts, T-shirts, and herringbone twill fatigue uniforms. Footwear consisted of one pair each of cushion sole socks and leather combat boots. In the comparison of the treadmill with walking on the hard-surfaced road, a load of 46 pounds consisting of a packboard with a high placed gravel load in metal cans and steel oxygen cylinder were used.

f. In a further study, four subjects walked indoors on a treadmill with a belt speed of 3-1/2 mph and outdoors on a cinder track at the same speed. In addition to herringbone twill fatigue uniforms and leather combat boots, the subjects wore eight-pound nylon vest armor. This second group of subjects did not carry pack loads.

g. The physical characteristics of the subjects used in these two studies are given in Table I.

TABLE I: CHARACTERISTICS OF SUBJECTS

Subject	Age (yrs.)	Height (cm.)	Weight (lbs.)	Weight (kg.)	Body Fat* %	Surface Area m^2
Ma	22	168	138	63	7.6	1.70
Ca	22	178	177	80	13.4	1.92
Mi	23	170	148	67	5.8	1.78
Hd	22	170	136	62	7.3	1.68
Hc	23	169	165	75	7.8	1.86
Sm	20	172	158	72	14.7	1.85
My	30	167	112	51	1.2	1.54
Br	24	170	135	61	7.9	1.70
Va	28	179	149	68	2.5	1.86
Wi	27	176	164	74	10.0	1.91
Gi	22	171	147	67	4.6	1.78
Pe	22	169	141	64	6.9	1.74
Me	23	169	137	62	2.5	1.70

*Determined by the skin-fold method

3. <u>Results</u>

a. A comparison of metabolic rate determinations by the closed system Tissot spirometer and the Douglas Bag and Haldane methods is given in Table II. Since no statistically significant systematic error between the two methods was found, comparison of data collected by the two different methods appeared justifiable.

TABLE II: COMPARISON OF OPEN AND CLOSED SYSTEMS OF METABOLIC RATE DETERMINATIONS ON TWO SUBJECTS WALKING ON A MOTOR-DRIVEN TREADMILL AT 3-1/2 MPH
(in cc. of oxygen per minute)

Tissot	average	Douglas Bag	Difference
Subject Va			
987 963	975	918	+57
810 968	889	981	-92
947 965	956	945	+11
962 890	926	924	+2
905 887	896	931	-35
936 892	914	905	+9
938	938	921	+17
880	880	844	+36
Mean	921.8	921.1	+0.7
t = .03 difference not significant			
Subject Wi			
900 1057	978	1114	-136
1126	1126	1071	+55
1072 1072	1072	1002	+70
1048	1048	1042	+6
Mean	1056	1057.2	-0.8
t = no difference			

b. In all subjects a higher energy cost was found for walking on the level road than on the treadmill. The results expressed as cc. of oxygen consumed per minute are given in Table III.

TABLE III: AVERAGE METABOLIC RATES (in cc. O_2/min.) ON TREADMILL AND ROAD AT 3-1/2 MPH WITH 46-POUND (20.9 kg.) PACKS

Subject	Road	Treadmill
Ma	1364*	1227***
Ca	1498**	1463***
Mi	1407*	1272***
Hd	1425	1166**
Hc	1523	1447**
Sm	1365	1349*
My	1240	1212*
Br	1593	1368***
Mean	1426.9	1313.0

Difference Means = 113.9
Percent Difference = 5
$t = 3.508$
$P < .01$ Highly Significant

*Mean of two determinations
**Mean of three determinations
***Mean of four or more determinations

c. The metabolic rate expressed as Calories/m²/hr. is given in Table IV and Figure 1.

d. Using four kilograms as a common weight of clothing and combat boots for all men, the metabolic rate expressed as cc. of oxygen per horizontal kilogrammeter is given in Table V.

e. The second experiment in which men walking at 3-1/2 mph on the treadmill were compared with themselves walking at the same speed on a cinder track again demonstrated the greater energy requirement for forward locomotion than for walking at the same nominal speed on a motor-driven horizontal treadmill. The outdoor studies were done at 21° and 18° C. (70° and 64° F.). The results obtained are given in Table VI. The cost of walking on the cinder track averaged 10.3 percent higher than walking on a treadmill with same belt speed.

TABLE IV: COMPARISON OF METABOLIC COST (in Cal./m^2/hr.) OF WALKING ON TREADMILL WITH ROAD AT 3-1/2 MPH CARRYING 46-POUND PACKS

Subject	Road	Treadmill
Ma	230	206
Ca	224	219
Mi	227	206
Hd	244	200
Hc	236	224
Sm	214	211
My	232	226
Br	270	232
Mean	234.6	215.5

Difference Means = 19.1
Percent Difference = 8.9
t = 3.487
P < .01 Highly Significant

ENERGY COST OF CARRYING A 46-POUND LOAD ON A MOTOR-DRIVEN TREADMILL COMPARED TO CARRYING THE SAME LOAD ON A LEVEL ASPHALT ROAD AT 3-½ mph

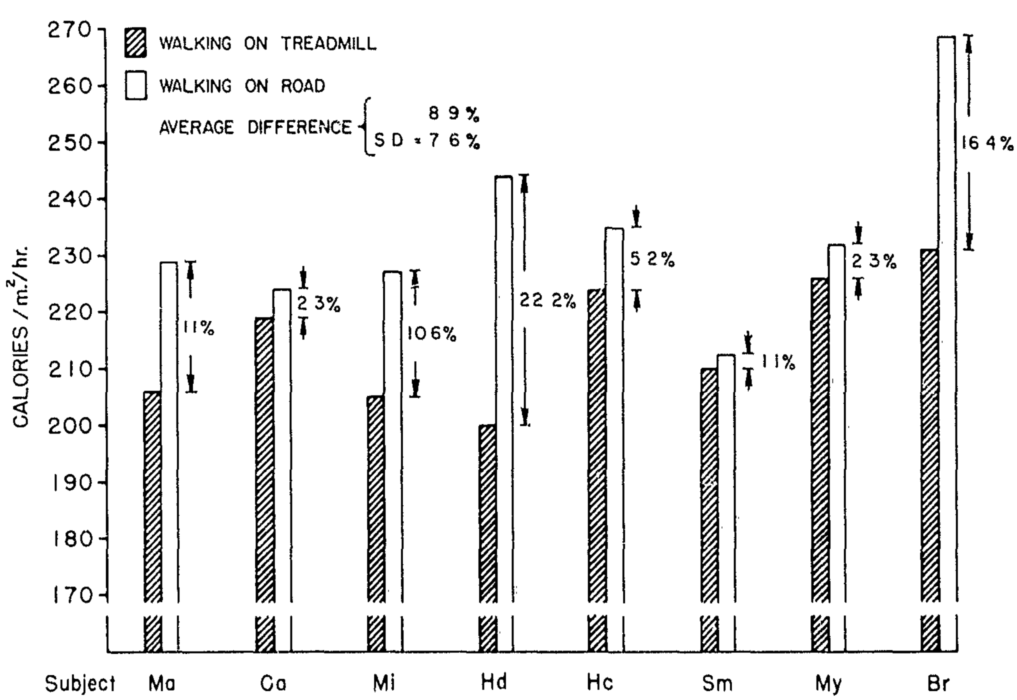

FIGURE 1

TABLE V: METABOLIC RATE IN CC. OF OXYGEN PER HORIZONTAL KILOGRAMMETER*

Subject	Road	Treadmill
Ma	.1662	.1492
Ca	.1555	.1521
Mi	.1601	.1448
Hd	.1791	.1467
Hc	.1678	.1596
Sm	.1521	.1503
My	.1769	.1729
Br	.1981	.1702
Mean	.1695	.1557

Percent Difference = 8.9
$t = 3.374$
$P < .02$ Significant

*Man + Clothing + Load moved forward one meter

TABLE VI: COMPARISON OF ENERGY EXPENDITURE AT 3-1/2 MPH WHILE WALKING ON A TREADMILL AND ON A CINDER TRACK WITH EIGHT-POUND VEST ARMOR

Subject	cc. O_2/minute			
	Treadmill	Mean	Track	Mean
Gi	980,1006,1020,985	998	1121,1252	1186
Pe	1317,1298,1165	1260	1289,1218	1254
Ma	1086,1021,969,1016	1023	1165,1141	1153
Me	1077,1055,1130,1258,1262,1129	1152	1355,1210	1283
Mean		1108.2		1219.0

Difference Means = 111.8
Percent Difference = 10.0

$t = 2.689$
P < Not Significant

	Calories/m.^{2}/hour	
Gi	163	194
Pe	208	208
Ma	173	195
Me	195	217
Mean	184.8	203.5

Difference Means = 18.7
Percent Difference = 10.1

$t = 2.841$
P < Not Significant

4. Discussion

a. It may be argued that the difference between load-carrying on a horizontal treadmill and on a road surface resulted from small irregularities of road surface as compared to the belt moving over the smooth wooden slipway. The asphalt road had very few loose pebbles and very little gross unevenness. Ideally, this comparison should be made between a subject walking on a moving treadmill and also on the same treadmill belt over a solid wooden floor of the same elastic properties as the bed of the treadmill. Despite these limitations, it is the consensus of the authors, based on their findings in this report and general observation of subjects walking on treadmills, that there is a distinct difference in the body mechanics of treadmill walking and of walking under normal conditions.

b. On inspection, it appears that treadmill walking includes some features which may explain the lesser energy cost when compared to road walking. These are only speculative until further studies have been conducted. With treadmill walking the center of gravity of the body, instead of progressing forward in a series of arcs of rise and fall in relation to the surface of the ground, oscillates back and forth in an arc over a fixed distance. It is suggested that by this means there is recovery of kinetic energy from the oscillating extremities on a larger scale than in ordinary walking and that less extra force from the ground for forward motion of the center of gravity, as described by Elftmann,[6,7] is required. When observing a subject walking on a treadmill one is struck with the somewhat slapping gait, and the amount of vertical rise of the body. It is conceivable that some of the energy used in the vertical rise is derived from the motion of the treadmill. The subject slaps his foot down in the forward position, locks his knee, and, as his foot is carried backward by the treadmill, there is a vertical component to the resultant force. Part of the energy elevating the body may therefore be derived from the power of the motor which moves the treadmill belt.

c. Müller[10] studied the efficiency of treadmill walking and determined a value for the energy requirement of forward progression by applying forward and backward pull at the hips. He found minimal expenditure at about three to four kilograms of forward pull. He further observed that forward pull in excess of this amount up to seven kilograms did not lead to an increased energy requirement for braking. This was explained by the fact that the subjects compensated for the forward pull by leaning backward. It is of interest in this connection that some men may be observed to lean somewhat backward and "ride" the treadmill. This suggests that another feature of the body mechanics which differs in treadmill and ordinary walking may be that the treadmill contributes energy for the rotation of the body about the center of gravity in its transverse axis, applying a torque in a clockwise direction as viewed from the subject's right. This would be similar to the contribution to vertical lift from the treadmill belt.

d. The impressions of the body mechanics given are preliminary. Analysis of body mechanics during walking is not easy and methods for such analysis are not routinely developed.[6,7] Further work will, therefore, be necessary before the causes of the difference in energy cost here reported are completely explained.

e. The fact that treadmill and road walking differ in energy cost and apparently in body mechanics is unimportant in most uses of treadmills, such as providing a standard exercise period for rewarming during a cold room experiment. The error does become important in any situation where a comparison with field observations is desired. It appears that the treadmill is probably at minimal expenditure for walking and that walking over natural terrains will be higher by varying degrees, depending upon the unevenness, slipperiness, elasticity, and other characteristics of the natural surfaces. For example, Glasow and Müller[9] found that walking over a freshly plowed field required a 90 to 170 percent greater expenditure of energy than walking over an asphalt road.

5. Conclusion

It has been demonstrated that subjects carrying loads over an asphalt road and a cinder track at 3-1/2 mph have an average energy expenditure nine to ten percent greater than they do when carrying the same load on a treadmill with a belt speed of 3-1/2 mph.

6. Recommendation

That, until complete nomographs are worked out for the conversion of treadmill data to field conditions at different speeds and on different surfaces, a ten percent correction be applied from treadmill data to obtain an estimate of a minimal energy expenditure for walking at the same velocity under field conditions.

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